CARA Status and Upcoming Enhancements

Megan Johnson

NASA CARA Team

Spring 2017 A-Train Mission Operations Working Group (MOWG)

13-15 JUN 2017

Agenda

- CARA Operational Highlights
- CARA Software Enhancements
- CARA Statistics
- Questions and Discussion

CARA OPERATIONAL HIGHLIGHTS

CARA Operational Highlights

- **Launch Support/New Missions**
  - Worldview-4: 11/11/16
  - GOES-R: 11/20/16
  - CYGNSS (8 Spacecraft): 12/16/16
- **Upcoming launch support**
  - TESS: 08/01/17
  - TDRS-M: 08/03/17
  - GPIM: 09/01/17
  - ICESat-2: 10/01/17
  - ICON: 11/15/17
  - JPSS-1: FY-Q4 2017

CARA SOFTWARE STATUS

CAS 8.4: Major Release

- **CAS 8.4 was deployed on Dec 15, 2016**
- **This release addressed the following:**
  - Conversion of all automation services to MATLAB services
  - Internal logging updates and bug fixes
  - Automation speed increase
  - December 2016 leap second support
  - Probability of Collision updated to calculate both 2D (Foster) and 3D (Coppola) Pc values
  - New OD Quality algorithm used to rank conjunctions for COSA review
  - Report updates for 3D Pc (Summary reports, HIE briefing, Maneuver Screening)
  - Enhanced CCSDS OEM v2 ephemeris support
  - Enhanced Red Alert text message capability
  - CDM creation updates

CAS 8.4.1: CDM Delivery Patch

- **CAS 8.4.1 was deployed to operations on Mar 22, 2017**
- **CARA GSFC now generating and delivering CDMs to Space-Track**
  - CDMs now automatically generated vs. a manual process by the CARA OSAs at the JSpOC
  - CA predictions unchanged
  - Added Pc calculation
  - Added O/O Ephemeris Filename and O/O covariance (if provided)
  - Easily recognizable with CARA identifiers in file name and within CDM
  - Overall, saves time, minimizes resources, and reduces errors
- **Some missions may still receive CARA OSA generated CDMs or both**

CAS 8.4.2: VNB/Uncertainty Patch

- **CAS 8.4.2 was deployed to operations on May 4, 2017**
- **Reported Miss Sigma Values (RIC 1-sigma uncertainties) no longer include a projection into the 2D conjunction plane**
  - No change to Pc calculation inputs
- **Added VNB miss vector and uncertainty calculations**
  - New table rows added to Summary Report details section
  - VNB can also be generated with HIE Briefing and MSA
  - Most useful for HEO spacecraft

CAS 8.4.3: 2D/3D Pc Patch

- **CAS 8.4.3 was deployed to operations on TBD**
- **Discrepancies Between 3D Pc Estimates and advanced Monte Carlo Equinoctial-Sampling Pc Estimates discovered**
- **Fix actions implemented including updates to CA Summary reports**
  - Reports higher of either 2D or 3D Pc
  - Adds both 2D and 3D Pc values to Details section of CA Summary reports
  - Differing values in HIEs validated with Monte Carlo in HIE Briefings

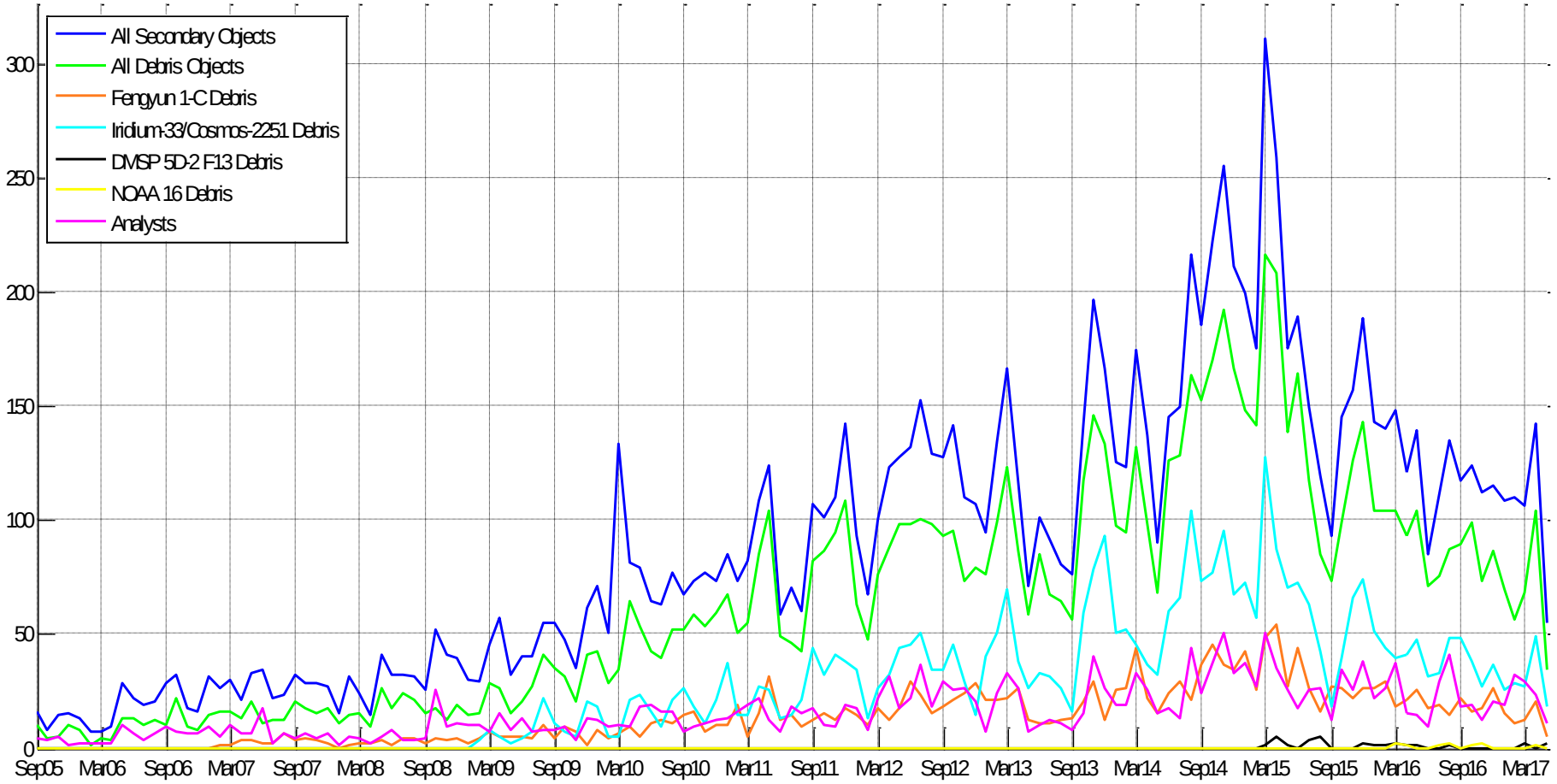
Upcoming Release

- **CAS 9.0**
  - System preparation for Space Fence with automation streamlining
  - Update to 9-digit SatIDs
  - Release NET FY18 Q4

CARA STATISTICS

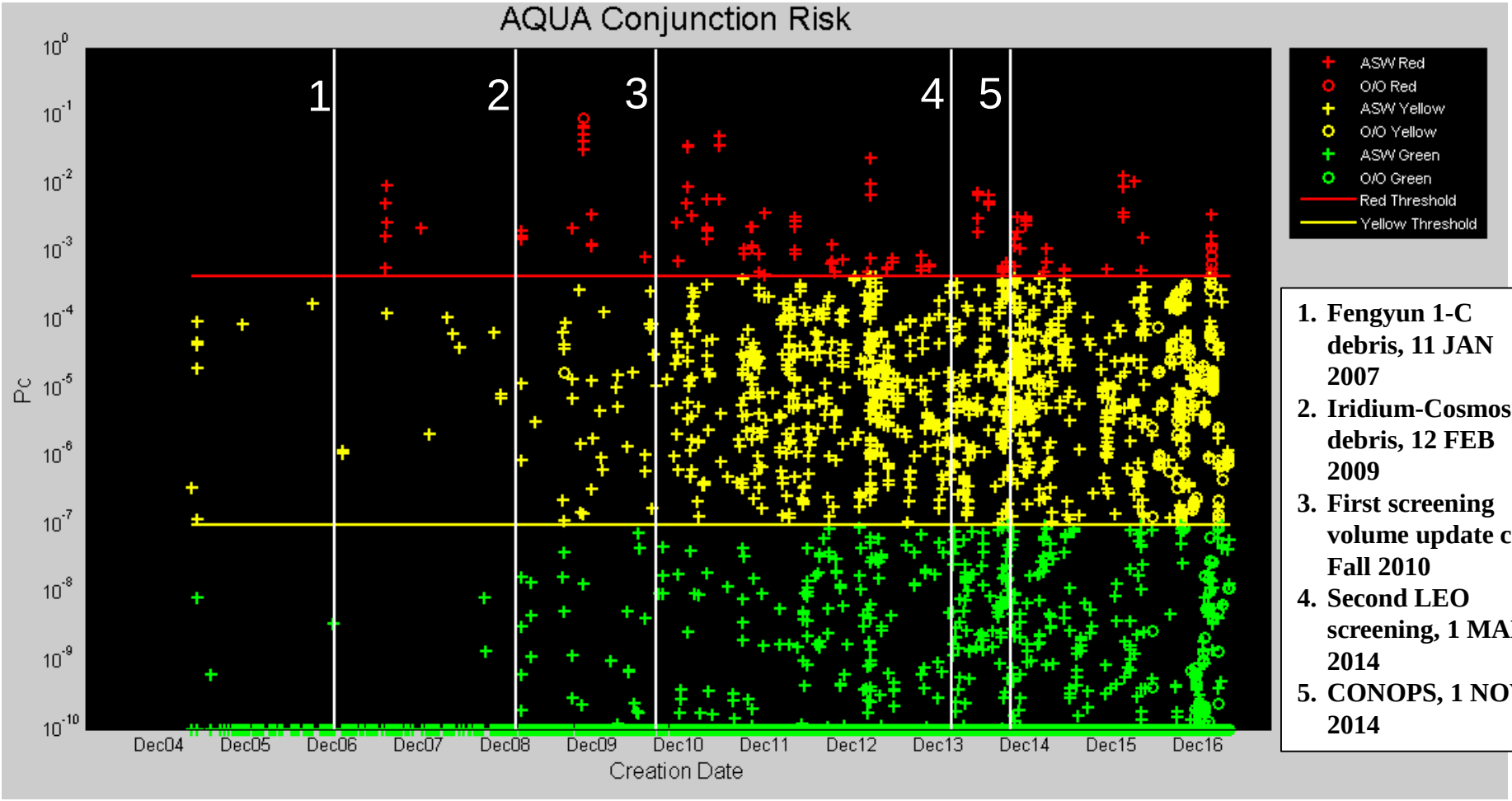
Number of Conjunctions with Current ESC Missions

Unique Events within 0.5x5x5-km Volume by Object Type



Note: Plot does not include Landsat-7, Landsat-8, or EO-1

Representative Historical Events by Risk Category



1. **Fengyun 1-C debris, 11 JAN 2007**
2. **Iridium-Cosmos debris, 12 FEB 2009**
3. **First screening volume update ca. Fall 2010**
4. **Second LEO screening, 1 MAR 2014**
5. **CONOPS, 1 NOV 2014**

High Interest Events*: 1 Aug 2016 through 15 May 2017

*LandSat-7 and -8 not considered

- **Tier 1: Notify O/O (email/phone call)**
  - **21** events
- **Tier 2: Brief O/O (HIE package/MTS/Sensor Coverage)**
  - **24** events
- **Tier 3: Ephemeris Screening**
  - **15** events
- **Tier 4: Execute mitigation action/waive/replan maneuver**
  - 8 events (4 RMMs; 4 Re-plan)
  - One RMM or waive/replan of nominal maneuver every ~36 days
  - Same as ~36 days (5 events) last MOWG (Feb 2016 – Aug 2016)
  - Decrease from ~16 days (13 events) MOWG (Jun 2015 – Feb 2016)
- **Total Work Tier events: 68**
  - ~2 events per week, on average for ESC (past results: 3,4,6 events per week)

Totals are for 8 of CARA's ~65 missions
- Total CARA work tier events: **156** (of which **68** are ESC)
- Total CARA work tier 3 & 4: **38** (of which **23** are ESC)

Cumulative Work Tier Stats (Historical through 15 May 2017, 2017 YTD)

Historical	Work Tier 1	Work Tier 2	Work Tier 3	Work Tier 4	Total
Landsat 5	31	3	4	5	43
Landsat 7	60	19	9	16	104
Terra	89	27	23	17	156
EO-1	53	13	9	2	77
SAC-C	33	3	2	1	39
Aqua	91	39	34	23	187
Aura	110	42	33	21	206
Parasol	58	6	6	4	74
CloudSat	68	7	11	17	103
CALIPSO	129	3	4	9	145
SAC-D	27	4	12	9	52
GCOM-W1	37	9	12	14	72
Landsat 8	83	6	11	9	109
OCO-2	16	17	12	9	54
Total	917	206	184	162	1469

Work Tier Definitions

1 – Email or phone notification

2 – HIE briefing, MTS, or Sensor Coverage

3 – Maneuver Screening

4 – Execute Maneuver or Waive/Replan existing maneuver

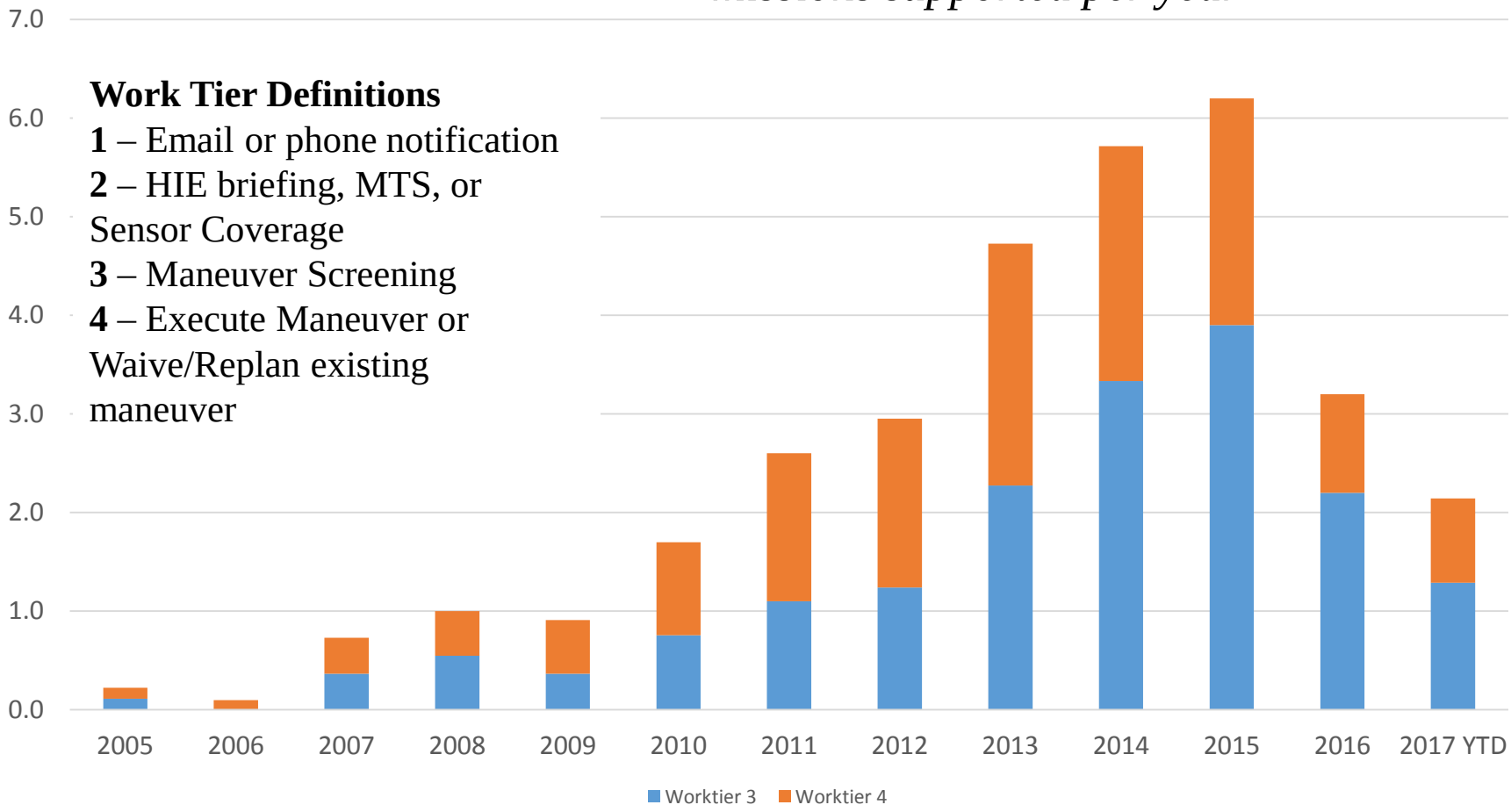
*Note that Tier 1 statistics are incomplete for Jan. 2005 – Aug. 2010. They were compiled using all past records on file and do not account for all events monitored during said time period.

**LandSat-7 and -8 not considered for 2017 YTD stats

2017 YTD	Work Tier 1	Work Tier 2	Work Tier 3	Work Tier 4	Total
Terra	1	1	0	0	2
EO-1	0	3	0	0	3
Aqua	2	0	2	0	4
Aura	0	3	2	2	7
CloudSat	0	0	0	0	0
CALIPSO	1	0	0	0	1
GCOM-W1	3	0	1	1	5
OCO-2	0	4	4	2	10
Total	7	11	9	6	33

HIE History for 705-km Constellations (Through 15 May 2017)

Normalized by no. of constellation missions supported per year



Work Tier Definitions

1 – Email or phone notification

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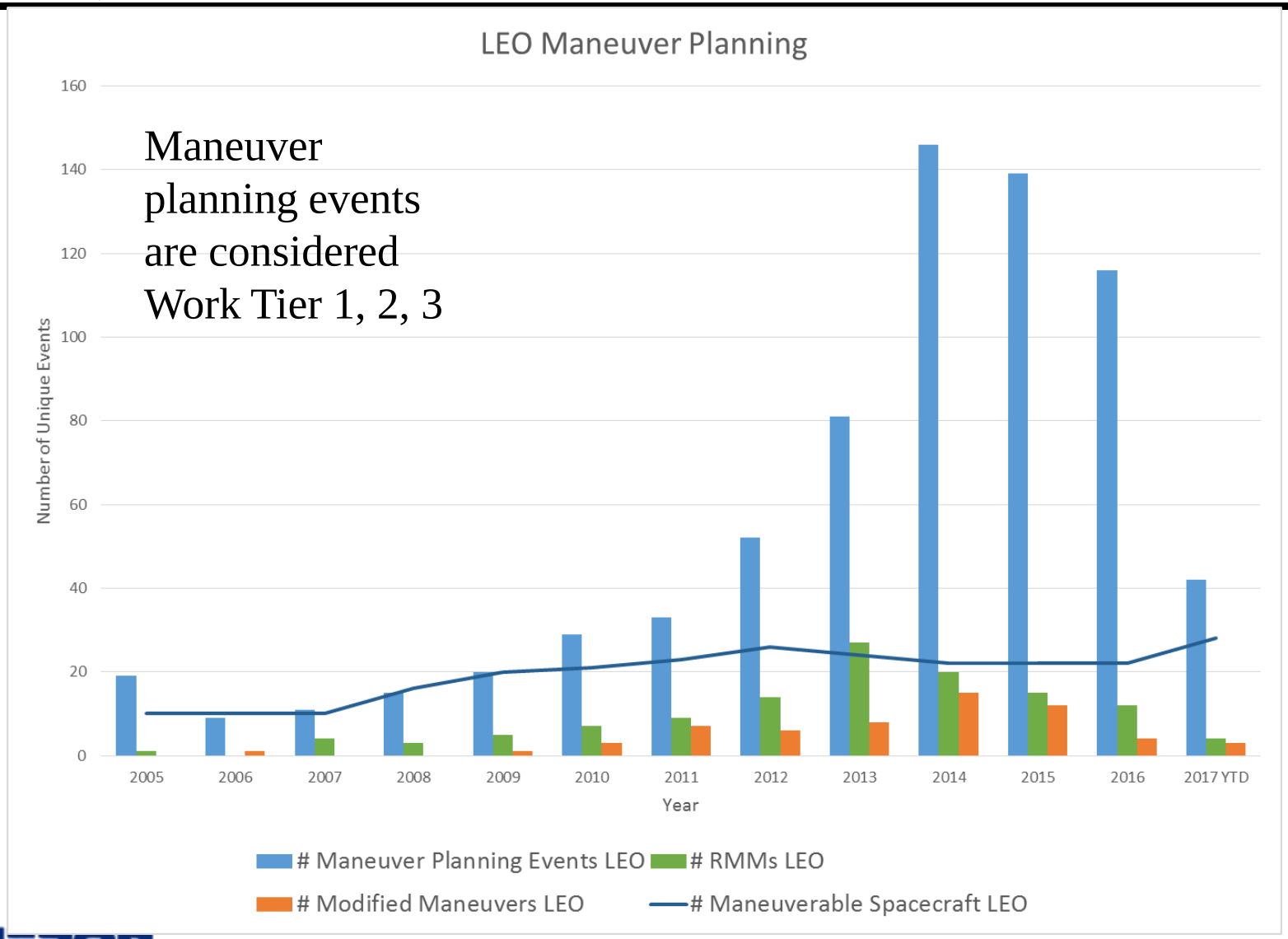
LEO Spacecraft Planning Effort Over Time



New Risk Mitigation Maneuvers (RMMs) for 705-km Constellations

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed [m] (ASW)	Maximum Pc Observed (ASW)	Minimum Miss Distance Observed [m] (OO)	Maximum Pc Observed (OO)	Maximum F-value Observed
Landsat-7	SL-24 Deb (37796)	15 Sep 2016	16 Sep 2016 13:28	4.2	9.68E-02	2.3	4.09E-02	9.7
GCOM-W1	UNKNOWN (88203)	29 Sep 2016	30 Sep 2016 17:47	186	3.32E-03	341	2.91E-03	7.2
CALIPSO	METEOR 1-10 Deb (08826)	23 Dec 2016	23 Dec 2016 01:44	24	6.51E-03	33	4.97E-03	9.3
GCOM-W1	UNKNOWN (89231)	11 Jan 2017	11 Jan 2017 15:19	540	1.29E-03	742	1.20E-03	6.8
Aura	PSLV R/B (25759)	26 Mar 2017	26 Mar 2017 13:39	95	3.45E-02	304	5.14E-03	9.6

Updated as of May 2017

Re-planned, Postponed, Waived Off Maneuvers (705-km Constellations)

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed [m] (ASW)	Maximum Pc Observed (ASW)	Minimum Miss Distance Observed [m] (OO)	Maximum Pc Observed (OO)	Maximum F-value Observed
Aura	Fengyun 1C Deb (32228)	12 Oct 2016	17 Oct 2016 14:25	522	7.65E-07	275	9.43E-05	4.8
OCO-2	Fengyun 1C Deb (32228)	07 Jan 2017	10 Jan 2017 07:53	15739	4.03E-07	3586	2.02E-05	4.3
OCO-2	(UNKNOWN) 82511	09 Jan 2017	11 Jan 2017 12:50	113	9.56E-05	211	7.01E-05	5.2
Aura	THOR ABLESTAR Deb (18908)	26 Apr 2017	28 Apr 2017 17:27	8233	7.84E-05	33	2.88E-03	7.6

Updated as of May 2017

Delayed-Notice Event Frequency

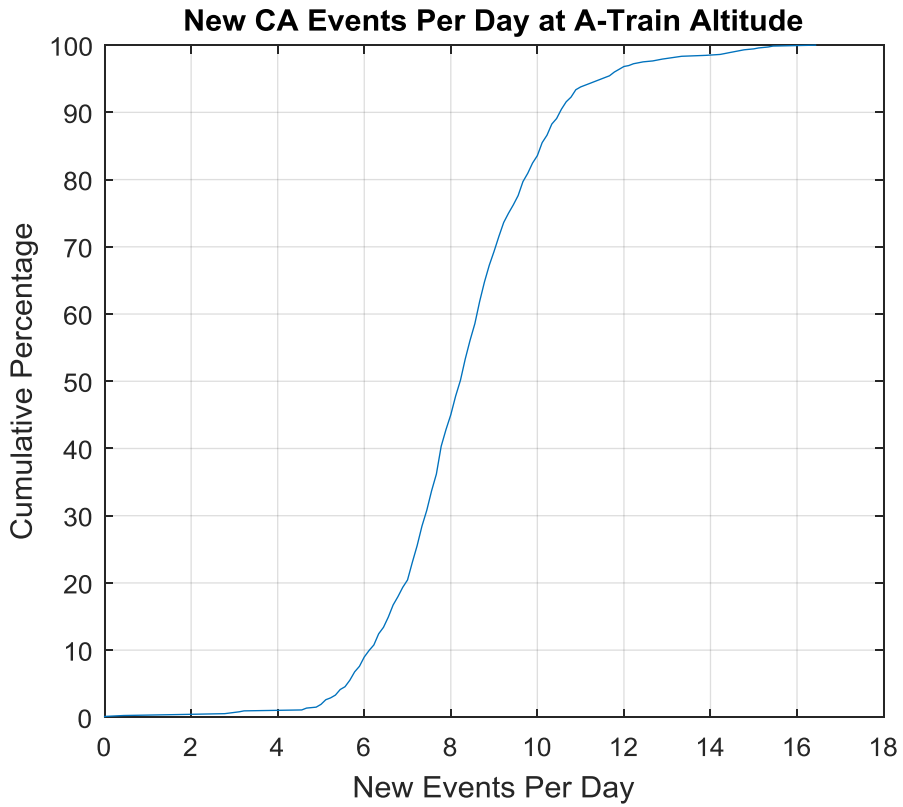
- **Historical data examined for nine spacecraft**
  - Landsat-7, Terra, Aqua, Aura, Cloudsat, CALIPSO, GCOM-W1,Landsat-8, OCO-2
- **Two-year data period used**
  - 1 APR 2015 – 1 APR 2017
- **For all events, divide event history into two temporal periods**
  - 5 to 7 days from TCA
  - Less than 5 days to TCA

Max Pc 7 to 5 Days to TCA	Max Pc 5 to 0 Days to TCA	% of All Events
Never Red	Never Red	98.44%
Red	Red	0.61%
Yellow	Red	0.67%
Green	Red	0.11%
Not in volume	Red	0.17%

- **Given "green" and "not in volume" constitute delayed-notice, then such cases total about 0.3% of all events**

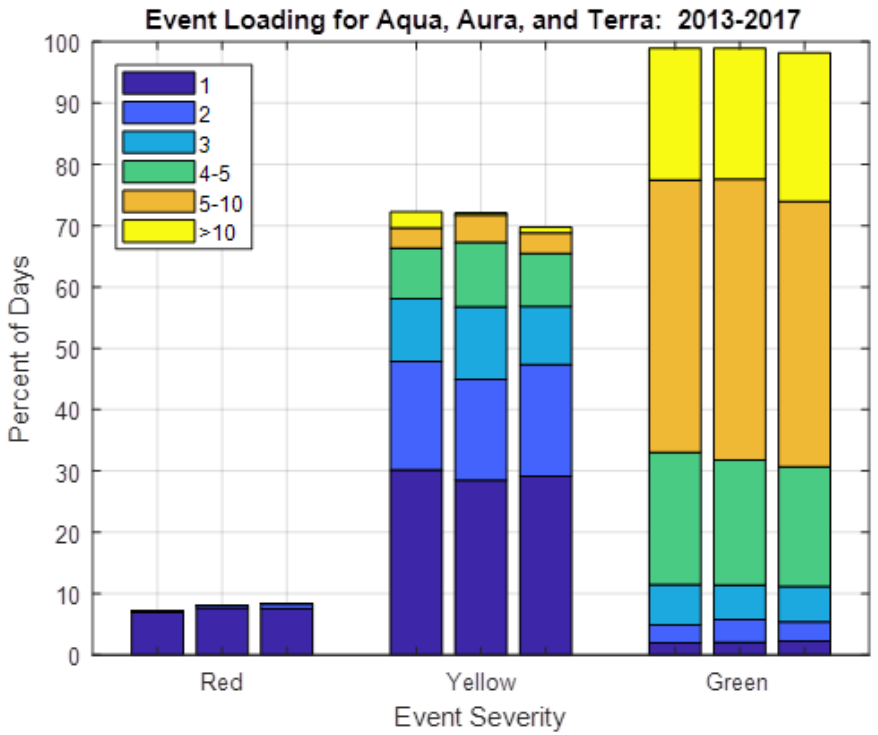
Daily New Event Frequency

- **CDF plot of total new events per day per spacecraft at A-Train altitude**
  - Landsat-7, Terra, Aqua, Aura, Cloudsat, CALIPSO, GCOM-W1,Landsat-8, OCO-2
  - Same as previous slide
- **~8 new events per day at 50ile**
- **~12 new events per day at 95ile**



Daily Moderate or High Pc Event Frequency

- **Plot of total moderate or high Pc events per day per spacecraft for Aqua, Aura, Terra**
  - Spacecraft used for previous portion of study at 705 km altitude
  - Estimates number of non-trivial events seen on any given day
- **~10% of days have a high Pc event at some point in the screening window**
- **~70% of days have a moderate Pc event at some point in the screening window**



OPEN DISCUSSION

BACKUP

Risk Mitigation Maneuvers for 705-km Constellations

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed (m)	Maximum Pc Observed	Maximum F-value Observed
Terra	SCOUT G-1	10/21/2005	10/23/2005 20:53	37	8.20E-02	9.97
PARASOL	AnalystSat	1/16/2007	1/17/2007 8:43	43	1.80E-02	8.91
Terra	FengYun 1-C Debris	6/22/2007	6/23/2007 21:44	18	1.60E-01	8.73
CloudSat	SINAH 1	7/4/2007	7/6/2007 6:51	38	4.70E-02	9.22
Aura	TRIAD 1 Debris	6/26/2008	6/27/2008 15:34	11	4.80E-01	9.62
CloudSat	Delta I Debris	7/20/2008	7/21/2008 4:38	90	2.90E-03	8.48
PARASOL	Fengyun 1-C Debris	10/19/2008	10/20/2008 10:59	82	2.10E-02	6.42
CloudSat	Cosmos 2251	4/23/2009	4/24/2009 13:29	52	4.80E-02	9.82
EO-1	SL-16 Debris	5/11/2009	5/12/2009 16:59	43	1.60E-02	8.11
PARASOL	Fengyun 1-C Debris	9/29/2009	9/30/2009 10:54	9	1.20E-01	8.81
Aqua	Fengyun 1-C Debris	11/25/2009	11/26/2009 15:36	25	7.00E-02	9.23

Risk Mitigation Maneuvers for 705-km Constellations cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed (m)	Maximum Pc Observed	Maximum F-value Observed
Landsat-7	FORMOSAT 3D	12/11/2009	12/16/2009 18:54	92	2.30E-02	9.07
Terra	Iridium 33 Debris	1/22/2010	1/23/2010 20:46	244	5.70E-03	8.15
Landsat-5	AnalystSat	4/1/2010	4/1/2010 20:49	68	5.50E-03	7.6
CloudSat	AnalystSat	8/17/10 & 8/18/10	8/18/2010 5:25	34.9	1.17E-02	7.1
Landsat-5	Cosmos 2251 Debris	8/24/2010	8/27/2010 12:58	55.8	5.15E-03	7.6
CloudSat	SL-16 Debris	10/11/2010	10/12/2010 4:15	230	3.80E-03	8.9
CloudSat	Cosmos 2251 Debris	10/13/2010	10/13/2010 23:58	1560	4.25E-03	6.2
Aura	Cosmos 2251 Debris	11/22/2010	11/24/2010 11:16	50	3.90E-02	9.5
Aqua	Cosmos 2251 Debris	1/2/2011	1/5/2011 18:17	94	8.40E-03	6.4
Aqua	Iridium 33 Debris	2/8/2011	2/8/2011 19:32	41	4.70E-02	8.6
CALIPSO	OV2-1	2/18/2011	2/19/2011 20:47	95	2.20E-04	9
Aqua	Thorad Agena D Debris	3/1/2011	3/2/2011 2:45	204	3.41E-03	9

Risk Mitigation Maneuvers for 705-km Constellations cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed (m)	Maximum Pc Observed	Maximum F-value Observed
CloudSat	Aqua	6/18/2011	7/1/2011 0:13	280	UNK	N/A
CloudSat	Terra	10/6/2011	11/7/2011 0:33	1125	UNK	UNK
Landsat-7	Cosmos 374 Debris	11/29/2011	11/30/2011 18:07	92	4.75E-03	7
CloudSat	FengYun 1-C Debris	12/14/2011	12/15/2011 18:59	220	1.79E-02	UNK
Landsat-7	FengYun 1-C Debris	3/8/2012	3/9/2012 19:32	498	2.02E-03	9.1
Landsat-7	Meteor 1-10 Debris	4/17/2012	4/18/2012 8:14	32	3.73E-02	7.8
Aura	Cosmos 2251 Debris	5/16/2012	5/17/2012 19:09	81	4.70E-04	8
Landsat-5	Thorad Agena D Debris	6/29/2012	7/1/2012 1:46	34	5.42E-03	9
CloudSat	SINAH 1	9/7/2012	9/8/2012 4:57	61	3.55E-03	9.2
GCOM-W1	Fengyun 1C Debris	9/8/2012	9/8/2012 21:18	241	1.59E-03	7.3

Risk Mitigation Maneuvers for 705-km Constellations cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed (m)	Maximum Pc Observed	Maximum F-value Observed
GCOM-W1	SL-16 Debris	9/25/2012	9/25/2012 20:54	125	4.68E-03	8.4
CALIPSO	Cosmos 2251 Debris	10/2/2012	10/2/2012 22:28	5	5.90E-02	9.6
PARASOL	SL-16 Debris	11/25/2012	11/25/2012 18:45	78	8.32E-03	8.6
CALIPSO	Cosmos 2251 Debris	1/5/2013	1/6/2013 13:51	94	2.43E-03	8.7
Landsat-5	AnalystSat	2/12/2013	2/13/2013 12:29	58	5.86E-03	7.5
Aqua	Thor Ablestar Debris	3/10/2013	3/12/2013 4:02	74	2.57E-03	8.5
CALIPSO	Iridium 33 Debris	3/20/2013	3/20/2013 22:23	129	5.72E-03	9.3
Aqua	Iridium 33 Debris	3/23/2013	3/23/2013 11:17	329	3.92E-04	6.4
Terra	Cosmos 1174 Debris	3/24/2013	3/26/2013 4:24	113	2.38E-03	9.3
CloudSat	Fengyun 1C Debris	4/25/2013	4/26/2013 11:39	529	1.37e-03	6.8
LDCM	NOAA 13 Debris	5/5/2013	5/6/2013 19:53	248	1.96E-02	9.6
Landsat-7	CZ-4 Debris	5/9/2013	5/10/2013 14:21	128	5.14E-04	8.9

Risk Mitigation Maneuvers for 705-km Constellations cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed (m)	Maximum Pc Observed	Maximum F-value Observed
GCOM-W1	CZ-4 Debris	10 May 2013	11 May 2013 22:24	69	6.81E-03	7.4
GCOM-W1	Fengyun 1C Debris	23 Jun 2013	25 Jun 2013 13:00	162	5.58E-03	9.4
Landsat 8	AnalystSat	15 Aug 2013	16 Aug 2013 11:39	1250	1.28E-03	6.4
Terra	CZ-4 Debris	18 Aug 2013	19 Aug 2013 07:43	79	6.72E-02	9.3
Aura	SJ-11-02	02 Sep 2013	03 Sep 2013 07:02	320	2.23E-04	8.5
GCOM-W1	Fengyun 1C Debris	19 Sep 2013	20 Sep 2013 05:55	184	1.69E-03	7.2
CALIPSO	Cosmos 397 Debris	24 Sep 2013	24 Sep 2013 18:31	115	2.42E-03	8.3
Landsat 7	SL-8 Debris	01 Oct 2013	02 Oct 2013 20:53	58	7.51E-04	8.7
Aqua	Iridium 33 Debris	25 Oct 2013	25 Oct 2013 04:27	689	8.99E-04	8.8
Terra	Fengyun 1C Debris	17 Nov 2013	18 Nov 2013 05:42	272	1.01E-02	8.5

Risk Mitigation Maneuvers for 705-km Constellations cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed (m)	Maximum Pc Observed	Maximum F-value Observed
Aqua	Cosmos 2251 Debris	28 Nov 2013	28 Nov 2013 22:28	373	6.41E-04	8.1
Terra	CZ-4 Debris	10 Feb 2014	10 Feb 2014 11:52	152	1.24E-02	8.5
Terra	Delta 1 Debris	2014 Mar 21	23 Mar 2014 00:17	50	2.35E-03	8.6
Landsat 7	Delta 1 Debris	2014 Apr 15	16 Apr 2014 17:10	362	8.63E-03	9.1
GCOM-W1	Iridium 33 Debris	2014 Apr 22	22 Apr 2014 17:11	223	3.39E-03	8.0
Landsat 7	Cosmos 2251 Debris	27 May 2014	28 May 2014 06:19	127	2.31E-02	8.4
OCO-2	AnalystSat	24 Aug 2014	24 Aug 2014 01:47	147	8.84E-04	6.5
Landsat 8	Cosmost 2251 Debris	28 Aug 2014	30 Aug 2014 19:15	384	3.02E-03	9.1
Aura	Fengyun 1C Debris	29 Aug 2014	02 Sep 2014 12:32	408	1.19E-03	6.7
OCO-2	CZ-4B Debris	14 Sep 2014	14 Sep 2014 22:51	81	2.84E-04	7.8
Landsat 7	SL-8 Debris	25 Sep 2014	25 Sep 2014 22:47	1447	4.16E-04	7.1

Risk Mitigation Maneuvers for 705-km Constellations cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed (m)	Maximum Pc Observed
GCOM-W1	SL-16 Debris	12 Oct 2014	13 Oct 2014 08:03	1900	6.75E-04
Aqua	Unknown	21 Oct 2014	21 Oct 2014 04:17	4935	6.90E-04
GCOM-W1	Cosmos 1275 Debris	09 Nov 2014	09 Nov 2014 23:44	69	3.91E-03
Terra	Iridium 33 Debris	31 Dec 2014	01 Jan 2015 06:24	206	9.67E-04
OCO-2	Cosmos 2251 Debris	01 Jan 2015	02 Jan 2015 07:58	152	6.70E-04
CloudSat	SL-8 Debris	14 Mar 2015	15 Mar 2015 20:07	40	3.72E-04
Landsat 8	Cosmos 2251 Debris	10 Apr 2015	10 Apr 2015 14:37	46	8.68E-04
GCOM-W1	DMSP 5D-2 F11 Debris	13 Apr 2015	13 Apr 2015 06:06	1439	1.46E-03
GCOM-W1	SJ-11-01	20 May 2015	22 May 2015 14:27	455	2.27E-03
Terra	Cosmos 2251 Debris	27 May 2015	27 May 2015 23:13	57	1.86E-02

New Risk Mitigation Maneuvers (RMMs) for 705-km Constellations

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Min. ASW Miss Distance (m)	Max. ASW Pc	Min. O/O Miss Distance (m)	Max. O/O Pc
Terra	87692 (UNKNOWN)	16 Jun 2015	16 Jun 2015 08:33	70	5.26E-2	147	2.19E-2
OCO-2	26093 (COSMOS 2251 DEB)	21 Nov 2015	22 Nov 2015 18:27	40	7.36E-4	137	6.54E-4
OCO-2	20435 (SL-8 DEB)	10 Dec 2015	10 Dec 2015 20:03	7	1.09E-1	13	8.13E-3
Landsat-7	00478 (THOR ABLESTAR DEB)	28 Dec 2015	29 Dec 2015 06:48	25	2.99E-2	64	3.03E-2
Aura	34215 (CBERS 1 DEB)	18 Jan 2016	19 Jan 2016 01:17	143	1.57E-3	138	1.35E-3

Updated as of JAN 2016

New Risk Mitigation Maneuvers (RMMs) for 705-km Constellations

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Min. ASW Miss Distance (m)	Max. ASW Pc	Min. O/O Miss Distance (m)	Max. O/O Pc
CALIPSO	28740 (CZ-2D Deb)	04 Mar 2016	04 Mar 2016 05:50	37	2.12E-02	55	3.42E-03
Aura*	34726 (COSMOS 2251 Deb)	15 Mar 2016	16 Mar 2016 08:27	19	3.36E-01	5	5.17E-01
OCO-2	35072 (COSMOS 2251 Deb)	12 Apr 2016	13 Apr 2016 00:27	4.5	4.97E-04	182	4.81E-04
Landsat-8	81293 (Unknown)	24 Apr 2016	24 Apr 2016 23:51	116	6.43E-04	33	5.82E-04
GCOM-W1	36543 (COSMOS 2251 Deb)	08 Jun 2016	08 Jun 2016 23:24	40	3.68E-03	102	6.73E-3

*The Aura event was both a waived maneuver (INC#46) and an RMM

Updated as of Aug 2016

Re-planned, Postponed, Waived Off Maneuvers (705-km Constellations)

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed O/O (m)	Minimum Miss Distance Observed ASW (m)	Maximum Pc Observed
Terra	Titan 3C Transtage Debris	UNK	1/12/2006 17:46	88	334	0.00E+00
Aura	Titan 3C Transtage Debris	6/17/2008	6/13/2008 3:26	618	5671	N/A
Aura	DMSP 5D-2 F11 debris	6/17/2008	6/15/2008 20:34	628	7340	N/A
Landsat-7	Fengyun 1-C debris	2/3/2009	1/14/2009 9:49	380	1055	5.13E-05
CALIPSO	CZ-4 Debris	11/23/2010	11/23/2010 3:12	1735	421	1.60E-03
CloudSat	Monitor-E/SL-19	11/23/2010	11/23/2010 13:47	150	1377	0.00E+00
Landsat-7	AnalystSat	12/21/2010	12/21/2010 19:43	673	441	2.35E-03
Aqua	CloudSat	6/8/2011	5/22/2011 0:00	UNK	UNK	UNK
Aqua	Fengyun 1-C debris	6/23/2011	6/23/2011 17:27	370	66	4.92E-02
Aqua	COSMOS 2251 Debris	8/25/2011	8/29/2011 3:57	195	30739	0.00E+00
Aura	COSMOS 2251 Debris	9/8/2011	9/3/2011 5:57	40	50	2.20E-03
Landsat-7	CZ-2C Debris	10/6/2011	10/9/2011 1:16	87	3860	1.68E-06

Re-planned, Postponed, Waived Off Maneuvers (705-km Constellations) cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed O/O (m)	Minimum Miss Distance Observed ASW (m)	Maximum Pc Observed
Aqua	CZ-4 Debris	10/25/2011	10/26/2011 11:13	12	1349	1.80E-03
Aqua	Titan 3C Transtage Debris	12/20/2011	12/16/2011 19:36	388	45775	0.00E+00
Terra	Nigeriasat-2	5/31/2012	6/1/2012 22:49	190	19970	0.00E+00
Landsat-7	Fengyun 1-C Debris	6/19/2012	6/21/2012 13:40	415	641	1.01E-04
GCOM-W1	Iridium 33 Debris	6/28/2012	6/29/2012 6:23	3487	4397	N/A
Aura	AnalystSat	8/29/2012	9/2/2012 13:28	230	63	2.74E-03
Landsat-5	COSMOS 2251 Debris	9/13/2012	9/11/2012 17:47	103	97	4.83E-03
Aqua	AnalystSat	9/13/2012	9/16/2012 18:50	63005	345	0.00E+00
Aqua	COSMOS 2251 Debris	1/25/2013	1/28/2013 19:46	235	190	3.23E-04
Aura	Latinsat B	4/3/2013	3/24/2013 22:04	793	5096	7.28E-16
Aura	SL-16 Debris	4/3/2013	3/30/2013 3:08	80	20095	3.24E-103
LDCM	Atlas Centaur R/B	4/3/2013	4/4/2013 4:11	227	5707	1.88E-52

Re-planned, Postponed, Waived Off Maneuvers (705-km Constellations) cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed O/O (m)	Minimum Miss Distance Observed ASW (m)	Maximum Pc Observed
Aqua	PSLV Debris	30 Apr 2013	24 Apr 2013 07:44	238	3810	6.63E-08
Landsat 8	SL-8 Debris	21 Jul 2013	23 Jul 2013 19:56	1549	266	1.26E-03
Landsat 8	NOAA 13 Debris	26 Sep 2013	28 Sep 2013 03:16	271	209	1.44E-08
Aura	Cosmos 2251 Debris	15 Nov 2013	18 Nov 2013 17:50	157	3822	1.27E-02
Aqua	SL-16 Debris	14 Jan 2014	09 Jan 2014 23:30	1402	3355	2.50E-05
Aqua	Cosmos 2251 Debris	14 Jan 2014	14 Jan 2014 17:24	7979	2930	4.06E-06
Terra	Magion 2	26 Feb 2014	26 Feb 2014 02:42	280	6806	1.14E-06
GCOM-W1	CZ-2D Debris	02 Apr 2014	27 Mar 2014 16:06	1454	11725	1.82E-04
CloudSat	AnalystSat	04 Apr 2014	03 Apr 2014 22:42	211	10269	1.30E-04
CloudSat	Thor Ablestar Debris	21 May 2014	22 May 2014 12:02	152	1199	9.00E-06
Aura	Cosmos 2251 Debris	19 Jun 2014	20 Jun 2014 05:22	137	64	8.80E-05
Landsat 8	Cosmos 2251 Debris	24 Sep 2014	24 Sep 2014 01:52	154	2628	0.00E+00

Re-planned, Postponed, Waived Off Maneuvers (705-km Constellations) cont.

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Minimum Miss Distance Observed O/O (m)	Minimum Miss Distance Observed ASW (m)	Maximum Pc Observed
Terra	Cosmos 2251 Debris	13 Nov 2014	08 Nov 2014 22:46	133	6067	0.00E+00
Calipso	CZ-2C Debris	05 Dec 2014	06 Dec 2014 06:49	1409	N/A	N/A
Terra	Iridium 33 Debris	12 Dec 2014	13 Dec 2014 15:44	4110	4320	2.13E-04
Aura	Fengyun 1-C debris	28 Jan 2015	24 Jan 2015 13:34	1292	1460	6.82E-04
Aura	CZ-2C Debris	28 Feb 2015	07 Feb 2015 02:16	298	153	1.04E-03
Aura	CBERS 1 Debris	28 Feb 2015	18 Feb 2015 22:36	150	607	6.06E-09
Aqua	Cosmos 2251 Debris	22 May 2015	22 May 2015 23:47	149	395	1.24E-04

Re-planned, Postponed, Waived Off Maneuvers (705-km Constellations)

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Min ASW Miss Distance (m)	Max ASW Pc	Min O/O Miss Distance (m)	Max O/O Pc
Landsat 7	30844 (Fengyun 1C debris)	25 Jun 2015	25 Jun 2015 02:01	3766	3.26E-05	310	2.76E-4
Aqua	21544 (Delta 1 Debris)	15 Oct 2015	10 Oct 2015 20:46	122	2.27E-04	1439	1.92E-4
Aura	32344 (Fengyun 1C Debris)	10 Nov 2015	06 Nov 2015 10:08	2056	4.55E-05	576	3.25E-4
CloudSat	34378 (Iridium 33 Debris)	19 Nov 2015	19 Nov 2015 19:00	33113	0.00E+00	2009	2.95E-5
Aqua	00253 (Thor Ablestar Debris)	20 Nov 2015	21 Nov 2015 11:13	N/A	N/A	647	8.71E-4
Aqua	22475 (SL-16 Debris)	16 Dec 2015	16 Dec 2015 16:16	480	7.90E-04	799	8.93E-4
Terra	34155 (Iridium 33 Debris)	18 Dec 2015	18 Dec 2015 15:31	3682	1.47E-03	1020	8.08E-4
OCO-2	38016 (Iridium 33 Debris)	30 Dec 2015	24 Dec 2015 16:05	15531	8.59E-5	11680	6.69E-06

Updated as of JAN 2016

Re-planned, Postponed, Waived Off Maneuvers (705-km Constellations)

Primary Object	Secondary Object	Maneuver Date	TCA (GMT)	Min. ASW Miss Distance (m)	Max. ASW Pc	Min. O/O Miss Distance (m)	Max. O/O Pc
Aura*	34726 (COSMOS 2251 Deb)	15 Mar 2016	16 Mar 2016 08:27	19	3.36E-01	5	5.17E-01

*The Aura event was both a waived maneuver (INC#46) and an RMM

Updated as of Aug 2016

Normalizing HIE Trend Data

Year	No. of Missions	Notes
2005	9	L5, L7, Terra, Aqua, Aura, EO-1, Parasol, SAC-C, IceSAT
2006	10.5	Added CALIPSO and PARASOL in April; 0.75 yrs each
2007	11	
2008	11	
2009	11	
2010	10.6	Stopped supporting IceSAT in August
2011	10	
2012	10.5	Added GCOM-W1 in May
2013	11	Added L8 in February; dropped Landsat 5 in June
2014	10.5	Added OCO-2 in July; dropped SAC-C, PARASOL
2015	10	
2016	10	
2017	7	Removed Landsat-7 and 8 Nov 1 2016, EO-1 decommissions Apr 1 2017